# THE NICKEL BULLETIN

## A MONTHLY SUMMARY OF CURRENT INFORMATION

**OCTOBER/NOVEMBER, 1956**


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THE MOND NICKEL COMPANY LTD • THAMES HOUSE, MILLBANK, LONDON, S.W.1
Telephone:- Victoria 3888

# ABSTRACTS OF CURRENT PUBLISHED INFORMATION ON NICKEL AND ITS ALLOYS

## GENERAL

### Rolling Ultra-Thin Metal Foil of Nickel-containing Alloys

'Rolling Ultra-Thin Metal Foil.'

*N.R.D.C. Bull.*, 1956, No. 7, Sept., pp. 26–7.

During recent years a demand has arisen in the electronics industry for ultra-thin foil for use in manufacture of magnetic amplifiers, capacitors, potentiometers, thermionic valves and printed circuits. The metals called for in such thin section include nickel-iron alloys, tantalum, molybdenum, and copper-nickel alloys, in the form of strip 2–4 in. wide and having a thickness of the order of 0·0001 in. It is required that the finished material be free from perforations, and be produced to very close tolerances: any appreciable waviness or variation in thickness is inadmissible.

The production of such fine strip is impossible on an ordinary cold-rolling mill, and until recently there was only one machine, of a very expensive type, which could turn out material in this thin section. Work in the Post Office Engineering Department has now resulted in the development of an attachment which can be fixed to existing two-high mills, and tests in other Government department research stations have confirmed the value of the invention.

Essentially, the device consists in using two subsidiary rollers of comparatively small diameter ($\frac{3}{16}$ in. – $\frac{7}{8}$ in. diameter is usually suitable) which are so located that they are frictionally driven by the main rolls throughout their length. These small rolls are angularly disposed to the vertical plane of the main drive rolls and are maintained in this position by thrust and end plates in the form of a nest, which limits their distortion under working conditions. The strip is processed only by these auxiliary rollers, which are subjected, by the main rolls, to a wedging action. The thinness to which the strip is rolled is governed by the diameter of the work rolls, the pressure exerted on them through the mill action, and the tension applied to the strip by the take-up.

Applications for patent coverage in several countries has been made by the National Research Development Corporation, which is arranging for commercial application of the invention.

### Apparatus for Studying Chemisorption

See abstract on p. 181.

## NICKEL

### Nickel in Canada

W. R. McCLELLAND: 'Nickel in Canada, with a Survey of World Conditions.'

*Canad. Dept. Mines and Technical Surveys, Mines Branch, Memo. Series No.* 130, 1955; 53 pp. Price 50 cents.

A comprehensive record, the scope of which is shown below:—

*Introduction*, including notes on the early history of nickel and its present significance as an industrial metal.

*History of Nickel Development in Canada*, containing the story from the first discovery in Canada, in 1848, to the most recent developments.

*Canadian Nickel Occurrences.* Notes on the location of nickel-bearing ores in Canada and on the companies engaged in extraction and refining.

*Mining, Milling and Metallurgy of Nickel in Canada.* The methods employed in mining nickel ores in Canada range from open-pit to practically all the accepted methods of underground mining. Attention is directed to published reports of the methods used by The International Nickel Company and other companies operating in the Sudbury area: the main features only are noted in this report. In the section relating to the metallurgy of nickel an account is given of—

(1) The Orford and modified Orford Processes used by The International Nickel Company, and the electrolytic refining process employed at their Port Colborne refinery.

(2) The Mond Carbonyl Process.

(3) The Hybinette Process, as used by Falconbridge Nickel Mines, Ltd.

(4) The Ammonia Pressure Leach Process, used by Sherritt Gordon Mines, Ltd.

*World Resources.* The location and extent of world resources of sulphide ores, silicate and oxidized ores, and nickeliferous iron ores are reviewed.

*Economics of Nickel.* Statistics on production of Canadian nickel are given for the period 1889–1954. Canadian reserves are reviewed, and particulars are given of world production, consumption and prices over long periods.

*Principal Uses of Nickel.* Review of the use of the metal in the form of metallic nickel, in ferrous and non-ferrous materials of many types, in electrodeposited coatings, and in various salts and compounds.

### Corrosion of Nickel by Nitric Acid

T. G. O. BERG: 'Solution of Nickel in Nitric Acid.'
*Jnl. Chimie Physique*, 1956, vol. 54, pp. 154–62.

The rate of solution of nickel in nitric acid was measured at 0°, 15°, 25°, 35°, 45°, 55° and 65°C., in solutions of acid concentrations between 0·25 *N* and 14·5 *N*.

### Atmospheric Corrosion of Non-Ferrous Metals

See abstract on p. 197.

### Thermal and Electrical Conductivities of Nickel at Low Temperatures

W. R. G. KEMP, P. G. KLEMENS and G. K. WHITE: 'Thermal and Electrical Conductivities of Iron, Nickel, Titanium and Zirconium at Low Temperatures.'
*Australian Jnl. of Physics*, 1956, vol. 9, pp. 180–8.

Measurements are reported of the thermal and electrical conductivities of iron, nickel, titanium, and zirconium, down to 2°K. (−271°C.). The values found indicate that thermal conduction in pure iron and nickel is almost completely electronic.

### Chemisorption of Hydrogen on Nickel

P. W. SELWOOD: 'The Mechanism of Chemisorption: Hydrogen on Nickel. I.'
*Jnl. Amer. Chemical Soc.*, 1956, vol. 78, Aug., pp. 3893–7.

The author describes apparatus for simultaneous measurement of gas adsorption and of change of specific magnetization, as occurring, for example, when hydrogen is chemisorbed on a nickel catalyst. Some results are given on the direction of electron transfer during adsorption. Magnetization–volume isotherms are presented for the nickel-hydrogen system under various adsorption conditions, and it is shown that certain transitory phenomena occur when hydrogen is admitted to a nickel surface.

An advantage of the apparatus described is that it is readily adaptable to automatic recording.

### Nickel and Nickel-Alloy Welding Rods and Electrodes

See abstract on p. 185.

### Photometric Determination of Magnesium in Nickel

C. L. LUKE: 'Rapid Photometric Determination of Magnesium in Electronic Nickel.'
*Analytical Chemistry*, 1956, vol. 28, Sept., pp. 1443–5.

The photometric oxine – chloroform extraction method for determination of magnesium in nickel gives reliable results, but is time-consuming, due to the number of separations involved. Most of the nickel used for electronic purposes contains less than 0·01 per cent. calcium, and because interference due to this metal is not serious it was considered likely that the method could be much simplified if no attempt was made to remove the calcium. The experiments reported in this paper have confirmed this presumption.

By removing precipitable metals by co-precipitation with ferrous hydroxide, followed by masking of the nickel and various other metals with cyanide, the interference of small amounts of most metals can be eliminated. An appreciable excess of iron must be present in order to co-precipitate interferants. Gallium is not completely precipitated even in the presence of a large excess of iron, but this is not a serious difficulty, since nickel does not usually contain this element.

Interference due to nickel, cobalt, calcium, silver, gold and platinum metals can readily be eliminated by masking with cyanide. The influence of zinc and cadmium cannot be entirely suppressed by the limited amount of cyanide which can be tolerated in the oxine-extraction separation, but the amount of zinc and cadmium present in nickel is usually less than 0·01 per cent.

The accuracy of results obtained by this new rapid method compares favourably with that obtained by longer procedures and it has been possible to reduce the time required for analysis to about 15 minutes.

### Diallyldithiocarbamido-Hydrazine as a Reagent for Nickel

N. K. DUTT and K. P. SEN SARMA: 'Diallyldithiocarbamido-Hydrazine as an Analytical Reagent. Part II. Determination of Copper, Zinc and Nickel in the Presence of Iron and Uranium.'
*Analytical Chimica Acta*, 1956, vol. 15, Aug., pp. 102–4.

Part I described determination of copper, nickel, zinc and lead and their separation in binary mixtures under specified conditions of pH (see *Nickel Bulletin*, 1956, vol. 29, Nos. 8–9, p. 60).

In Part II it is shown that copper, zinc and nickel can be quantitatively precipitated by diallyldithiocarbamido-hydrazine, even in the presence of iron and uranium, when these elements are in only small quantities in the solution. Chloride and nitrate ions do not interfere.

The authors suggest that their method is also well suited for use in gravimetric analysis of brass and Monel.

### Nickel Oxide in Enamelling

T. B. YEE, J. S. MACHIN and A. I. ANDREWS: 'Relation of Composition to Viscosity of Enamel Glasses.'
*Jnl. Amer. Ceramic Soc.*, 1955, vol. 38, Oct., pp. 378–82.

The changes in the viscosities of a series of enamel glasses, which were produced by varying the CaF, $Fe_2O_3$, $TiO_2$, $Co_3O_4$, NiO, $MnO_2$, $FeSO_4$ and $NiSO_4$ contents, were examined over a range of temperatures which corresponded approximately to normal firing temperatures.

# ELECTRODEPOSITION AND OTHER COATING METHODS

### Electrode Reactions in Electrodeposition of Nickel

W. A. WESLEY: 'Of Nickel Atoms, Ions and Electrons.'
*Trans. Inst. Metal Finishing*, 1956, vol. 33, pp. 87–105; *Bull. Inst. Metal Finishing*, 1956, vol. 6, Summer issue.
Third Hothersall Memorial Lecture to the Institute of Metal Finishing.

In tribute to the work of Hothersall and his colleagues in 'pushing back the fog curtain which lies between the knowledge of electrode reactions and its practical application', the lecturer presented some speculations on the true nature of one reaction which is of importance in electrodeposition.

$$Ni \longrightarrow Ni^{++} + 2e \quad \text{Reaction I}$$

and its relation to the reaction which takes place at the cathode in the same cell:

$$Ni^{++} + 2e \longrightarrow Ni \quad \text{Reaction II}$$

In introducing his subject, Dr. Wesley made use of the Pourbaix diagram for the nickel-water system, and outlined the areas on the diagram in which the anode and cathode reactions for nickel electroplating take place, i.e., the normal limits of pH and potential for the process. The formation of nickel ions in the area of anode corrosion is not, however, a simple mechanism, since so few nickel atoms exist in the reactive condition in which the two-valency electrons occur in the 4*s* shell. Pure nickel anodes do, however, dissolve to a very limited extent at low potentials and low current density, due to the presence of a few of these reactive atoms, but as the current density is raised an intermediate passivity sets in (designated by the author condition β), in which the anode continues to dissolve but at a higher potential of about +0·4 volt. When chloride is excluded from the solution the anode-dissolution rate drops to a low level and the potential is further increased to the oxygen-evolution level of around +1·4 volts at quite low current densities. It is clear, therefore, that chloride acts as a catalyst and aids anode dissolution. Further, depolarized anodes, which are characterized by a small sulphur impurity content, dissolve evenly over a wide range of pH and current density, which indicates that in this case the impurity acts catalytically in promoting the solution of unreactive nickel atoms.

Dr. Wesley speculated on the mechanism of anode solution in the case of pure nickel in aqueous acid solutions and those containing some chloride.

The nickel atoms exist in the metallic state in three conditions: the first with no available conducting electrons, and a full 3*d* shell, containing 10 electrons; the second one with valency electron and one vacancy in the 3*d* shell, and the third with two 4*s* electrons and two vacancies in the 3*d* shell. The first type is unreactive and must undergo changes to make it reactive, whereby electrons are available in the 4*s* shell for current conduction, the condition under which electrolysis can take place. He proposes that the first step in Watts-type plating solutions is the formation of an adsorbed complex on the surface of the anode, by means of either the hydronium ion or the chloride ion. This step loosens the bond between the atom and its neighbours and, at the same time, releases a *d*-shell electron. Afterwards, the hydrogen ion splits off, leaving the atom in the intermediate stage, partially hydrated. The next step requires catalysis to complete the change to the hydrated nickel ion, with an atom core of 2 electron vacancies and two electrons available for current conduction.

Both cases of complexing, with hydrogen and chloride ions, are followed by the separation of the proton and chloride ion, leaving the nickel atom partially hydrated. The complexing ions are thus free for further work with unreactive nickel atoms.

Dr. Wesley suggests that depolarized anodes, which afford smooth corrosion at low overpotentials over a wide range of pH, etc., achieve their effect by the presence of a catalyst, such as sulphur. Other polyvalent elements, e.g., iron, manganese, phosphorus, arsenic, antimony, and others, should also be capable of exchanging electrons, as they change their state of valency, for the conversion of unreactive nickel to the active condition.

The diagram on page 183 summarizes the views postulated by Dr. Wesley.

### Deposition of Nickel by the Kanigen Process

A. McL. AITKEN: 'The Deposition of Nickel by Chemical Reduction.'
*Sheet Metal Industries*, 1956, vol. 33, July, pp. 439–43 and 455.

This paper, presented to the Conference on Modern Processes organized by the Sheet and Strip Metal Users' Technical Association, in April 1956, gives an account of the process developed by General American Transportation Corporation, of Chicago. The information given is based largely on reports by that Company, particularly those by Dr. G. Gutzeit, the Associate Director of the Research and Development Department of that Company (cf. paper by Gutzeit abstracted in *Nickel Bulletin*, 1956, vol. 29, No. 7, p. 128).

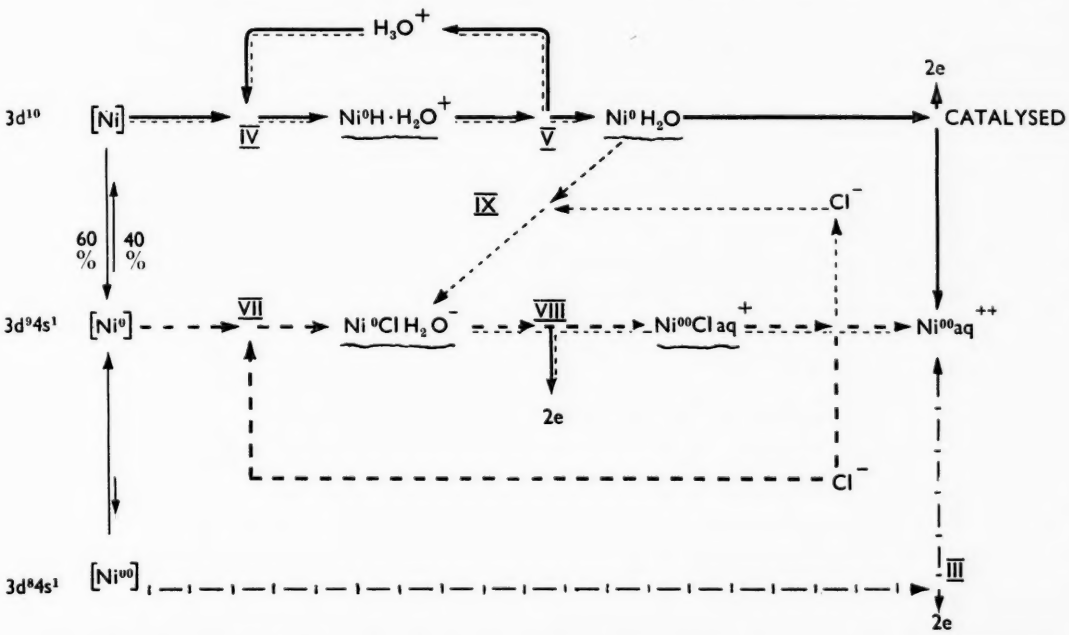
### Analysis of Bright Nickel-Plating Solutions

K. E. LANGFORD: 'Determination of Sodium Formate in Organic-Type Bright Nickel Solutions.'
*Electroplating and Metal Finishing*, 1956, vol. 9 Sept., p. 293.

The formate content of a nickel-plating solution is usually determined by removal of the nickel as hydroxide followed by oxidation of the solution by alkaline potassium permanganate. Excess permanganate not used in the reaction is then caused to react with potassium iodide and the liberated iodide is titrated with *N*/10 sodium-thiosulphate solution.

With nickel solutions containing sulphonamides, saccharin, coumarin, heterocyclic bases or other organic additions this procedure yields high results,

**MECHANISMS OF ANODIC DISSOLUTION OF NICKEL**




due to the oxidation of such compounds by the permanganate. It is possible, by employing a somewhat lengthy distillation method, to determine the formate with a high degree of accuracy, but it has been found that the more rapid and convenient alkaline permanganate oxidation method can be modified to give satisfactory results. It is recommended that after removal of the nickel as hydroxide the alkaline solution be heated with activated carbon, thus removing the interfering organic materials. The formate can then be determined as easily as in cobalt-nickel solutions. Formate (present as the sodium or nickel salt) is not adsorbed by activated carbon. Full details are given of analytical procedure.

## NON-FERROUS ALLOYS

### Preferred Orientation and Magnetic Properties of Nickel-containing Ductile Magnet Alloys

W. R. HIBBARD: 'Preferred Orientations and Magnetic Properties of Rolled and Annealed Permanent-Magnet Alloys.'

*Jnl. of Metals*, 1956, vol. 8, Aug., Sect. II: *Trans. Amer. Inst. Mining and Metallurgical Engineers*, pp. 962–7. T.P. 4160E.

In the general category of precipitation-hardening permanent-magnet alloys there is a group of ductile materials, including Cunife, Cunico, Silmanal, Heusler's Alloy and Vicalloy, which can be rolled and annealed to develop a preferred orientation in the crystals of the matrix. Some qualitative data have already been published on the rolling and annealing textures of Cunife and Vicalloy, but no pole figures had previously been available in the literature, and the part which precipitation plays in determining the characteristics of the alloys is still somewhat controversial.

The investigation now reported was carried out to obtain information which could be used to establish maximum preferred orientation, and to elucidate the extent to which the properties of the respective materials are associated with the matrix or with the precipitate. For alloys studied, see table on p. 184.

The following conclusions are drawn from the experimental results, which are presented in detail:—

In Cunife and in Vicalloy I distinct textures are associated with magnetic anisotropy, as measured by coercive force or torque curves. In Cunico, Silmanal and Vicalloy II distinct textures are associated with isotropic torque curves and in Heusler's Alloy nearly random textures are associated with nearly random properties.

No clear-cut conclusions could be reached regarding the rôle of shape anisotropy, magneto-crystalline anisotropy, or strain anisotropy of the precipitate as related to the single-domain theory of this type of permanent-magnet alloy. The data on Cunife, Cunico, and Silmanal are consistent with the concept of torque anisotropy at low fields being associated with the shape anisotropy of the precipitate particles, as suggested by NESBITT *et al.* (*Jnl. Applied Physics*, 1954, vol. 25, p. 1014). The effect of field strength on maximum torque suggests, however, that magnetocrystalline anisotropy plays a significant rôle.

**Composition of Ductile Permanent-Magnet Alloys**

**Wt. %**

| Alloy | Cu | Ni | Fe | Co | Mn | Ag | Al | V | W | Si |
|---|---|---|---|---|---|---|---|---|---|---|
| Cunife .. .. | Balance | 17·5 | 16·7 | — | — | — | — | — | — | — |
| Cunico .. .. | Balance | 21·0 | — | 28·5 | — | — | — | — | — | — |
| Silmanal .. .. | — | — | — | — | 8·1 | 87·5 | 4·3 | — | — | — |
| Vicalloy I .. | — | — | Balance | 52·4 | 0·3 | — | — | 8·9 | 1·9 | 0·6 |
| Vicalloy II .. | — | — | Balance | 55·8 | 0·3 | — | — | 12·9 | <0·1 | 0·6 |
| Heusler's Alloy .. | Balance | — | — | — | 14·1 | — | 9·6 | — | — | — |

### Structure of Titanium-Nickel Alloy

D. H. POLONIS and J. G. PARR: 'Orientation Relationships Between Alpha Prime and Beta Phases in a Ti-Ni Alloy.'

*Jnl. of Metals*, 1956, vol. 8, Aug., Sect. II: *Trans. Amer. Inst. Mining and Metallurgical Engineers*, pp. 892–3. T.N. 332E.

Orientation relationships in a titanium alloy containing 8 at. per cent. nickel were determined by the method of 'spotty' X-ray diffraction films. The principles of this technique are described, as based on the original work by PARR (*Acta Crystallographica*, 1952, vol. 5, p. 842).

### Influence of Nickel and Other Elements on Electrical Conductivity of Copper

F. PAWLEK and K. REICHEL: 'The Influence of Added Elements on the Electrical Conductivity of Copper. I. The Electrical Conductivity of Pure Copper.'

*Zeitsch. f. Metallkunde*, 1956, vol. 47, June, pp. 347–56.

*See also*—

F. PAWLEK, K. VIESSMANN and H. WENDT: 'The Influence of Addition Elements on the Electrical Conductivity of Copper. II. The Effect, on the Electrical Conductivity of Copper, of Various Metallic Impurities and of Oxygen', *ibid.*, pp. 357–63.

Part I deals with the electrical conductivity of high-purity copper made from sintered powder. It also contains a survey of data available on the solubility, in copper, of 49 elements, and on the increase in electrical resistance produced by the addition, to copper, of 30 different elements. The reviews of both aspects are well documented.

In Part II alloys in the following copper-base systems are discussed:—Cu-Ni-Sb, -Fe-As, -As-Pb, -Fe-Pb, complex quinary alloys.

A second section of this investigation covered the influence of oxygen on the specific electrical resistance of copper and of binary and ternary alloys of the following types:—Cu-Fe, -As, -Ni, -Sb, -Pb, -As-Fe, -Ni-Sb, -Pb-As. It is shown that the alloy elements have a cumulative effect on electrical resistance, so long as the alloy content is within the limit of solubility. When any one element is present in an amount exceeding its solubility in copper this simple relationship ceases to exist.

### Influence of Precipitation Hardening on the Electrical Resistance of Copper-Manganese-Nickel Alloys

K. L. DAHL: 'The Hardenability of Copper-Manganese-Nickel Alloys: II. Investigation of Electrical Resistance.'

*Zeitsch. f. Metallkunde*, 1956, vol. 47, June, pp. 370–8.

In the first part of this investigation, which was concerned with the hardness and structure of a series of copper-manganese-nickel alloys containing 10–60 per cent. nickel+manganese, it was indicated that electrical resistance fell sharply with increasing hardening (*ibid.*, 1954, vol. 45, p. 42: *Nickel Bulletin*, 1954, vol. 27, Nos. 7–8, p. 131).

This second paper reports a closer investigation of the influence of precipitation hardening on electrical resistance, in six alloys covering the same range of composition. The changes were studied as a function of time and temperature of heating.

The results confirmed the fall in electrical resistance which occurs on progressive precipitation hardening and showed also that even after maximum hardening has been obtained continued heating may cause a still further fall in electrical resistance. The changes in resistance are more nearly reversible than the hardening effects. The observations made with regard to electrical properties, especially temperature coefficient, appear to indicate that hardening is fundamentally associated with the formation of an ordered phase from the disordered solid solution.

### Resistance of Nickel-containing Bronzes to Attack by Softened Water

See abstract on p. 199.

### Nickel in Silver-base Alloys

W. WARREN: 'Hardenable Silver Alloy.'

*Materials and Methods*, 1956, vol. 44, Aug., pp. 106–7.

The article describes a precipitation-hardening alloy of the following nominal composition:—silver 99·50, magnesium 0·30, nickel 0·20, per cent.

The properties of the alloy at normal and at elevated temperatures are tabulated.

The alloy is hardened by a process of selective oxidation. After all forming operations have been completed the component is heated in an oxidizing atmosphere, preferably at 1350°F. (735°C.) for a period proportional to the thickness of the material. For parts which will not be subjected to stress at elevated temperatures an oxidation temperature of 1475°F. (800°C.) can be used. It is anticipated that the alloy in the form of strip, wire, rod and tube will find numerous applications in the electrical and electronic industries. Typical uses are suggested.

### Inconel-Cemented Titanium Carbide

J. R. LOW: 'Observations on the Brittle Fracture of Cemented Titanium Carbide.'

*Jnl. of Metals*, 1956, vol. 8, Aug., Sect. II: *Trans. Amer. Inst. Mining and Metallurgical Engineers*, pp. 982–4. T.N. 4196E.

The tests were made on a cermet prepared by infiltration of titanium carbide with Inconel (composition 50–50 per cent.). The material was tested at room temperature, in 0·4 mm. thick section. Deformation and fracture of the specimen was accomplished by bending it as a simply supported, centrally-loaded beam, in a bending fixture which could be placed in the stage of a microscope with the tension side of the bend specimen under the microscope objective.

Observation at various stages of deformation showed that up to 0·2 per cent. extension there was no perceptible change in the specimen, but at 0·3 per cent. extension a large number of cracked carbide particles were observed, located in a small wedge-shaped area near the mid-span of the bent specimen and extending in from one edge for a distance of about 3 mm.

In general all the cracks were oriented approximately perpendicular to the direction of the tensile stress. Photomicrographs at high magnification show that the brittle fracture occurs primarily as a result of cracking of the larger carbide particles, followed by cracking of adjacent smaller carbides, and finally by rupture of the Inconel matrix between cracked carbides. This last effect occurs at a strain of about 1·2 per cent.

No evidence was found of separation at the interface between the carbide and the matrix.

### Rolling Ultra-Thin Metal Foil of Nickel-containing Alloys

See abstract on p. 180.

### Nickel and Nickel-Alloy Welding Rods and Electrodes

AMER. WELDING SOC.: 'Tentative Specification for Nickel and Nickel-base Alloy Bare Welding Filler Metals.'

*A.W.S. Specn.* A 5.14–56T. (also issued as *A.S.T.M. Designation* A. 304–56T): Published 1956.

The specification covers bare filler metals (welding rods and electrodes) for the welding of nickel and high-nickel alloys containing more than 50 per cent. nickel, by the oxy-acetylene, atomic-hydrogen, inert-gas metal-arc (non-consumable electrode), inert-gas metal-arc (consumable electrode), and submerged-arc welding processes.

Details of the compositions specified are shown in the table on page 186.

### Welding of Cupro-Nickel Alloys

L. H. HAWTHORNE and R. F. BURTH: 'Welding the Cupro-Nickels by the Inert-Gas-Shielded Arc Processes.'

*Welding Jnl.*, 1956, vol. 35, Aug., pp. 401S–8S.

Cupro-nickel of the 70–30 type has been recognized for many years as offering particularly high resistance to corrosion and erosion. An outstanding application of the alloy has been for condenser tubes, for which a modified 70–30 material containing a small percentage of iron has proved specially suitable. More recently a lower-nickel alloy (copper 90, nickel 10, per cent.) has been introduced, and in some applications is proving acceptable as an alternative to the 70–30 type.

The 70–30 alloy has been successfully welded by the metal-arc process, but the higher thermal conductivity of the 90–10 alloy has presented some problems in welding. This paper makes recommendations on the welding of both types of alloy by the inert-gas-shielded tungsten-arc and the gas-shielded metal-arc processes. Filler metal of the composition shown below gives, on both alloys and in both processes, sound welds having good mechanical properties:—

| | % |
|---|---|
| Copper .. .. .. | 67·75 |
| Titanium .. .. .. | 0·23 |
| Silicon .. .. .. | 0·12 |
| Iron .. .. .. | 0·59 |
| Manganese .. .. | 0·77 |
| Aluminium .. .. | 0·06 |
| Nickel .. .. .. | Balance |

Such filler metal may be used for welding the two alloys to each other and also for joining either alloy to mild steel. No specialized modification of the technique normally used with the respective welding processes is called for.

The paper contains comprehensive information with regard to preferred joint design, welding currents, shielding gas, and operating techniques, and lists the mechanical properties of the joints which can be obtained under optimum conditions. Commercial applications for the welded materials are also considered.

### Nickel Alloys in Aircraft

See abstract on p. 192.

### Cobalt-base Alloys and Stainless Steels in Dentistry

See abstracts on p. 199.

## Welding Rods and Electrodes for Welding Nickel and High-Nickel Alloys

### Chemical Requirements

(Note.—Single values shown are maximum percentages, except where otherwise specified)

| AWS-ASTM Classification | Alloy | Carbon % | Manganese % | Iron % | Boron % | Sulphur % | Silicon % | Copper % | Nickel plus Cobalt* % | Cobalt % | Aluminium % | Titanium % | Chromium % | Niobium plus Tantalum % | Molybdenum % | Vanadium % | Tungsten % | Other Elements Total % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RN40 | Nickel-copper | 0·30 | 2·00 | 2·50 | — | 0·02 | 0·50 | remainder | 63·0–70·0 | — | — | — | — | — | — | — | — | 0·50 |
| ERN60 | Nickel-copper | 0·15 | 1·00 | 2·50 | — | 0·02 | 1·50 | remainder | 62·0–69·0 | — | 1·25 | 1·50–3·00 | — | — | — | — | — | 0·50 |
| RN41 | Nickel | 0·15 | 0·35 | 0·40 | — | 0·01 | 1·00 | 0·25 | 97·0 min. | — | — | 0·50 | — | — | — | — | — | 0·50 |
| ERN61 | Nickel | 0·15 | 1·00 | 1·00 | — | 0·01 | 0·75 | 0·25 | 93·0 min. | — | 1·50 | 2·00–3·50 | — | — | — | — | — | 0·50 |
| RN42 | Nickel-chromium-iron | 0·10 | 1·00 | 6·00–10·0 | — | 0·015 | 0·50 | 0·50 | 72·0 min. | — | — | — | 14·0–17·0 | — | — | — | — | 1·00 |
| ERN62 | Nickel-chromium-iron | 0·10 | 1·00 | 6·00–10·0 | — | 0·015 | 0·75 | 0·50 | 70·0 min. | — | — | — | 14·0–17·0 | 1·50–3·00 | — | — | — | 1·00 |
| RN43 | Nickel-copper-silicon | 0·30 | 1·00 | 1·00 | — | 0·02 | 0·50–1·50 | remainder | 55·0–60·0 | — | — | — | — | — | — | — | — | 0·50 |
| ERN64 | Nickel-copper-aluminium | 0·25 | 1·50 | 2·00 | — | 0·01 | 1·00 | remainder | 63·0–70·0 | — | 2·00–4·00 | 0·25–1·00 | — | — | — | — | — | 0·50 |
| ERN69 | Nickel-chromium-iron-titanium | 0·08 | 1·00 | 5·00–9·00 | — | 0·01 | 0·50 | 0·50 | 70·0 min. | — | 0·40–1·00 | 2·00–2·75 | 14·0–17·0 | 0·70–1·20 | — | — | — | 0·50 |
| ERN6N | Nickel-chromium-titanium | 0·08–0·15 | 1·00 | 2·00 | — | 0·015 | 0·30 | 0·50 | 75·0 min. | — | 0·40 | 0·15–0·50 | 19·0–21·0 | — | — | — | — | 0·50 |
| ERN7B | Nickel-molybdenum | 0·08 | 1·00 | 4·00–7·00 | 0·04 | 0·03 | 1·00 | — | remainder | 2·50 | — | — | 1·00 | — | 26·0–30·0 | 0·20–0·60 | — | 0·50 |
| ERN7C | Nickel-molybdenum-chromium | 0·08 | 1·00 | 4·00–7·00 | 0·04 | 0·03 | 1·00 | — | remainder | 2·50 | — | — | 14·5–16·5 | — | 15·0–17·0 | 0·35 | 3·00–4·50 | 0·50 |
| ERN7W | Nickel-molybdenum-chromium | 0·12 | 1·00 | 4·00–7·00 | 0·04 | 0·03 | 1·00 | — | remainder | 2·50 | — | — | 4·00–6·00 | — | 23·0–26·0 | 0·60 | — | 0·50 |

* Cobalt, if determined, 1·00 % max.

## NICKEL-IRON ALLOYS

### Gyromagnetic Ratios of Nickel-Iron Alloys

G. G. SCOTT: 'Gyromagnetic Ratios of the Iron-Nickel Alloys.'
*Physical Rev.*, 1956, vol. 103, Aug. 1, pp. 561–3.

Earlier communications (*ibid.*, 1955, vol. 99, pp. 1241 and 1824) dealt with the gyromagnetic ratios of nickel and of iron: see *Nickel Bulletin*, 1955, vol. 28, No. 12, p. 207. The present paper is concerned with experiments on nickel-iron rods in which the nickel contents were, respectively, 10, 25, 35, 50, 65, 75 and 90, per cent.

### Preferred Orientation and Magnetic Properties of Nickel-containing Ductile Magnet Alloys

See abstract on p. 183.

### Damping Phenomena in Nickel-Iron Alloys

R. OCHSENFELD: 'Damping in Iron-Nickel Alloys'. *Zeitsch. f. Physik*, 1955, vol. 143, Dec. 12, pp. 357–73.

Description of apparatus for measuring damping of flexural vibrations in strip of nickel-iron alloys. The experimental results are compared with those which would be anticipated on a theoretical basis.
*See also—*
R. OCHSENFELD: 'The Magneto-Elastic Properties of Some Ferromagnetic Nickel-Iron Alloys', *ibid.*, Dec. 22, pp. 375–91.

Study of changes in elastic modulus with magnetization and with amplitude of vibration, in strip of 36 and 60 per cent. nickel nickel-iron alloys.

### Rolling Ultra-Thin Metal Foil of Nickel-containing Alloys

See abstract on p. 180.

### Scaling of Nickel Steels and Nickel-Iron Alloy

See abstract on p. 191.

### Nickel-Iron Electrodes for Repair Welding of Marine Engineering Components

See abstract on p. 187.

## CAST IRON

### Welding of Cast Iron

AMER. WELDING SOC.: 'Tentative Specification for Welding Rods and Covered Electrodes for Welding Cast Iron.'
*A.W.S. Specn.* A5. 15–56T. (Also issued as *A.S.T.M. Designation* A398–56T): Published 1956.

The specification includes welding rods for oxy-acetylene and carbon-arc welding and covered electrodes for shielded metal-arc welding of cast iron. These filler metals are suitable for welding grey cast iron, malleable iron and some alloy cast irons.

The compositions specified include cast iron containing low percentages of nickel, nickel-containing bronzes, nickel-iron alloys, and nickel-copper alloys.

### Nickel-Iron Electrodes for Repair Welding of Marine Engineering Components

H. C. WAUGH: 'Welding Repair Costing $600 Reclaims $8,000 Engine Blocks.'
*Welding Jnl.*, 1956, vol. 35, Aug., pp. 801–3.

The following report has recently been made on the experience of a U.S. Shipping firm operating a large fleet of tugs.

'Marine Industries Ltd., Sorel, Quebec, operates a fleet of diesel-powered towing tugs and tankers, mostly in the St. Lawrence River and Gulf and along the Atlantic Coast. Formerly they replaced engine blocks with corroded or cracked guide rings, at a cost of about $8,000 each. Salvaging the blocks by welding costs an average of $600, a saving of about $7,400 per block. Since the welding procedure was first developed, about four years ago, the company has repaired 23 engine blocks, with a total saving amounting to over $150,000.

'The part requiring to be welded is the guide ring—a narrow circular shoulder inside the engine block near the top of each cylinder. The guide ring forms the top of the cooling-water jackets and also supports the removable cylinder sleeve or liner.

'After the engines have been in service for some time, the salt cooling water pumped through the water jackets corrodes the guide ring and destroys the important watertight seal. The water enters the combustion chamber, putting the engine out of commission. Sometimes, also, the guide ring simply cracks from normal long service. In either case, repair or replacement is necessary.

'The diesel engine blocks are made in three sections, each containing three cylinders, and in past years when the guide ring in one cylinder deteriorated a whole block section was replaced. The cost, including dismantling and re-assembly, amounted to approximately $8,000.'

This article describes the procedure developed for welding repair. The metal-arc welding process is employed, and a coated nickel-iron electrode (55 per cent. nickel and 45 per cent. iron) was chosen to meet the exacting requirements involved. This electrode consistently produces machinable weld deposits and has resulted in sound crack-free joints on the cylinder blocks.

## CONSTRUCTIONAL STEELS

### Isothermal-Transformation Diagrams of Nickel-Alloy Steels

BRIT. IRON AND STEEL RESEARCH ASSOCN.: 'Atlas of Isothermal-Transformation Diagrams of B.S. En Steels (2nd Edition).'
*Iron and Steel Inst. Special Report No.* 56, 1956; 157 pp.

The first edition of the Atlas of Isothermal Trans-

formation Diagrams for B.S. En steels was published by the Iron and Steel Institute in 1949: for note on scope see *Nickel Bulletin*, 1949, vol. 22, No. 7, p. 114.

Since that date there has been an increasing demand for information on the isothermal characteristics of further steels of the En series, particularly carburizing steels, and the Thermal Treatment Committee of the British Iron and Steel Research Association therefore undertook the preparation of additional diagrams. These diagrams are now presented as an integral part of the 2nd edition of the original Atlas.

The revision carried out for this purpose has included not only the insertion of diagrams for additional steels, but also the modification of a number of those previously published, in the light of clearer understanding of the significance of the experimental data on which they were based. Some changes have also been made in the arrangement of the Atlas.

The data presented are based on experimental work carried out in the laboratories of member firms who have placed their facilities at the disposal of the Thermal Treatment Committee.

The steels included in the 2nd edition are shown below: those marked with an asterisk are nickel-alloy steels.

*Direct-Hardening Steels*

| | |
|---|---|
| En 11 | En 25 * |
| „ 12 * | „ 26 * |
| „ 13 * | „ 28 * |
| „ 14B | „ 30B* |
| „ 15 | „ 31 |
| „ 16 | „ 40B |
| „ 17 | „ 42 |
| „ 18 | „ 44 |
| „ 19 | „ 45 |
| „ 20 | „ 47 |
| „ 21 * | „ 56 |
| „ 23 * | „ 100 * |
| „ 24 * | „ 110 * |
| | „ 111 * |

*Case-Hardening Steels*

| | |
|---|---|
| En 33 * | En 351 * |
| „ 34 * | „ 352 * |
| „ 36 * | „ 353 * |
| „ 39A* | „ 354 * |
| „ 39B* | „ 355 * |

**Hardenability Factors for Hypereutectoid Low-Alloy Steels**

E. J. WHITTENBERGER, R. R. BURT and D. J. CARNEY: 'Hardenability Factors for Hypereutectoid Low-Alloy Steels.'
*Jnl. of Metals*, 1956, vol. 8, Aug., Sect. II: *Trans. Amer. Inst. Mining and Metallurgical Engineers*, pp. 1008–16 T.P. 4185E.

The results of a large number of investigations carried out during recent years have established information which permits calculation of the hardenability of medium-carbon low-alloy steels from a knowledge of composition and grain size, and the data so obtained have been utilized in developing improved low-alloy steels on an economic basis. No parallel information is, however, available for application to high-carbon low-alloy steels, to which the hardenability factors for medium-carbon steels have been found to be inapplicable.

This paper reports studies of the subject on a range of steels of nominal 1 per cent. carbon types, in which bainite is the first sub-critical transformation product. The hardenability factors developed for the elements carbon, silicon, manganese, chromium, nickel and molybdenum permit calculation of 95, 80 and 50 per cent. martensite hardenability on quenching previously spheroidized steels from 1475°, 1525° and 1575°F. (800°, 830° and 855°C.). The multiplying factors were shown to be single-valued functions of the percentage of the respective elements present in the steels.

The especially strong contribution of silicon to hardenability in high-carbon low-alloy steels was found to be associated with the retarding effect of this element on the bainite reaction. It is suggested that the important influence of both silicon and manganese on hardenability indicates that increased amounts of these elements would be potentially useful as an economical means of achieving additional hardenability in high-carbon low-alloy steels.

**Bainite Transformation in 3½ per cent. Nickel-Chromium Steel**

L. S. BIRKS: 'Characteristics of the Bainite Transformation in a Ni-Cr Steel.' *Jnl. of Metals*, 1956, vol. 8, Aug. Sect., II: *Trans. Amer. Inst. Mining and Metallurgical Engineers*, pp. 989–93 T.P. 4287E.

The bainite transformation in a 3·5 per cent. nickel, 1·25 per cent. chromium steel was studied under various conditions of cooling and stress. The main observations made are summarized below:—

(1) Transformation in the bainite region (925°–575°F.: 495°–300°C.) is very little affected by the rate of cooling from the austenitizing temperature at 1600°F. (870°C.) to the upper limit of bainite transformation at 925°F. (495°C.).

(2) Starting time for the bainite transformation is of the same order of magnitude for isothermal transformation and continuous cooling, but rate of transformation is somewhat more rapid under isothermal conditions.

(3) Tensile stress accelerates transformation, under both isothermal and continuous-cooling conditions. A stress of 32,000 p.s.i. (14·25 tons per sq. in.) changes the isothermal-transformation diagram to a form which corresponds to the continuous-cooling diagram.

(4) Transformation for non-linear continuous cooling cannot be determined directly from the linear continuous-cooling diagram, but may be predicted by first assuming that the fractional amount of austenite transformed in a given narrow temperature interval depends on the approximate linear cooling rate during that interval, and then by summing up stepwise over the whole temperature range concerned.

### Influence of Quenching on Physical Properties of Steels

R. W. POWELL: 'The Effect of Quenching on the Thermal Conductivities and Electrical Resistivities of Steel.'

*Jnl. Iron and Steel Inst.*, 1956, vol. 184, Sept., pp. 6–10.

The work reported in this paper is supplementary to related investigations included in the Second Report of the Alloy Steels Research Committee (*Iron and Steel Inst. Special Report No.* 24, 1939, pp. 215–51) and *Jnl. Iron and Steel Inst.*, 1946, vol. 154, pp. 83P–121P.

The physical properties reported for the 22 steels included in the earlier work were determined on materials tested in conditions in which their properties were relatively stable and independent of the heat-treatment associated with the respective tests. The present paper demonstrates the effect of water-quenching on the steels used in the previous investigations. The types examined were as follows:

Carbon Steels (C 0·06–1·2 per cent.).

Low-Alloy Steels (Mn, Ni, Ni-Cr, Cr-Mn, Cr-Mn-Ni and Mn-Si types).

High-Alloy Steels (Mn, Mn-Ni, Cr-Ni, Cr, and Cr-W types).

On about one-half of the steels examined *increases* of 30 per cent. or more in electrical resistivity were obtained by water quenching, and it is believed that thermal conductivities would undergo *reduction* of a comparable order. Measurements made on one of the steels confirm this hypothesis.

Results are also given for the thermal conductivity and electrical resistivity of a sample of En 31 (high-carbon, chromium-molybdenum) steel. The electrical resistivity measurements made on this steel and on a 1·22 per cent. carbon steel after oil-quenching to temperatures of 135°–190°C. are recorded:

*See also*—

R. W. POWELL: 'The Effect of Oil Quenching and Tempering on the Thermal Conductivities and Electrical Resistivities of Three Steels', *ibid.*, pp. 10–17.

Report of a detailed investigation on the influence of quenching and tempering on the thermal conductivities and electrical resistivities of a high-carbon chromium-molybdenum steel (En 31), a 0·4 per cent. carbon steel (En 8), and a 1 per cent. chromium-molybdenum steel (En 19).

### Impact Properties of Quenched-and-Tempered Nickel-Alloy Steels

H. SCHWARTZBART and J. P. SHEEHAN: 'Impact Properties of Quenched-and-Tempered Alloy Steels.'

*Armour Research Foundation, Illinois Inst. Technology*, 1955, Sept. 19; 53 pp. + figures.

The report records the results of a comprehensive investigation of the fracture characteristics of eight representative structural alloy steels of commercial and laboratory production. The following types were included in the survey:—

Low manganese
„ nickel
„ nickel-chromium
„ chromium-molybdenum
„ nickel-chromium-molybdenum
„ nickel-molybdenum
„ chromium
Triple lean-alloy nickel-chromium-molybdenum

Specimens of these steels were quenched to give 100 per cent. martensite structure and were tempered at temperatures from 300° to 1200°F. (150° to 650°C.), to hardnesses of $R_c$ 55–$R_c$ 20. They were then tested at temperatures between −320° and +500°F. (−196° and +260°C.).

The following are some of the major conclusions:—

In all the steels a similarity of behaviour was noted with regard to variation of transition temperature and maximum energy with tempering temperature. All showed maximum transition temperatures when tempered in the range 500°–800°F. (260°–425°C.).

Nickel steels showed embrittlement after tempering at 1200°F. (650°C.), probably due to formation of austenite during tempering at that temperature, which austenite transforms to fresh martensite when the steel is quenched after tempering. After tempering at 1000°F. (540°C.) temper brittleness was observed in all high-carbon grades examined, except the straight-nickel type. In steels containing molybdenum the effect was less than in the molybdenum-free grades.

The transition temperature of a quenched-and-tempered steel is dependent, *inter alia*, on carbon content, alloy content, and tempering temperature. Curves correlating these variables are presented. It is shown that a carbon level of 0·30–0·40 per cent. gives the best overall compromise with regard to a minimum transition temperature and hardness. The four molybdenum-containing grades had the lowest transition temperatures, at most of the carbon contents, and over most of the hardness range. Phosphorus caused marked rise in transition temperature, but this was controllable, to some extent, by the ratio of molybdenum to phosphorus. Addition of boron lowered transition temperatures at high strength levels, due to its effect on '500°F. embrittlement', which is thus shifted to higher tempering temperatures.

Rare-earth additions offset the effect of sulphur, which lowers the maximum energy absorption of transverse specimens. In a low-alloy chromium-molybdenum steel the coarser the austenite grain size the higher was the transition temperature over a hardness range of 25–50 $R_c$: the effect of grain size was found to be greatest at high strength levels. Size and shape of ferrite grains also have a pronounced effect on transition temperature.

Transition temperature was lowered with decrease in size of specimen, and an effect of specimen size on maximum absorbed energy was also observed.

## Fatigue Investigations on Nickel-containing Materials

Papers presented at the International Conference on Fatigue of Metals, convened in September 1956 by The Institution of Mechanical Engineers in co-operation with the American Society of Mechanical Engineers, included reports containing reference to various types of nickel-containing steels and non-ferrous nickel alloys. The scope of some papers of interest in this connexion is shown below:

N. P. ALLEN and P. G. FORREST: 'The Influence of Temperature on the Fatigue of Metals.'

*Session* 4, Paper 1; 16 pp.

Until about 15 years ago very little fatigue testing was carried out at temperatures other than atmospheric, but more recently the development of the gas turbine and the use of aircraft at high altitudes have led to a demand for information on fatigue behaviour at both elevated and low temperatures. In most cases relevant data have comprised comparisons of the performance of materials of many kinds under somewhat closely specified conditions, and the information available relates usually to specialized alloys. Few systematic studies of the effect of temperature on the fatigue of metals over a wide range of conditions have been carried out.

The aim of the authors of this paper has been to assemble and critically survey records of individual investigations on various materials, as a preliminary basis for formulation of theory and general conclusions on the influence of temperature and other variables on fatigue characteristics of metals and alloys. The subject is considered in sections relating to the following aspects:—

Fatigue of various metals at room temperature; effect of temperature on the fatigue of copper and of mild steel; fatigue strength of technical creep-resisting alloys; the nature of fractures occurring at high temperature; fatigue under static and fluctuating stresses; correlation of creep strength and fatigue strength; influence of period of stress fluctuation; effect of metallographic structure; influence of corrosion; notch-sensitivity as a factor in fatigue; fatigue by thermally induced stresses.

The data presented in the respective sections include information on high-alloy steels and constructional steels containing nickel, nickel-base creep-resisting alloys, cupro-nickel, and aluminium alloys containing nickel.

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T. W. LOMAS, J. O. WARD, J. R. RAIT and E. W. COLBECK: 'The Influence of Frequency of Vibration on the Endurance Limit of Ferrous Alloys at Speeds up to 150,000 Cycles per Minute, using a Pneumatic Resonance System.'

*Session* 4, Paper 7; 13 pp.

This paper describes a machine developed for comparison of the fatigue properties of wrought and cast turbine blades under resonant conditions. As an introduction, the relevant literature (in a survey of which the authors have reviewed some 5,000 items) is considered, with *bibliographical* reference to a selective list of original investigations.

Design of the testing equipment is described and well illustrated, and a report is made on determinations of fatigue properties made by it on low-alloy nickel-chromium-molybdenum steels, high-chromium steels of straight and modified types, 12–25 per cent. nickel-chromium-(tungsten) steels, and 36–12 per cent. nickel-chromium steels. The results establish that there is a definite influence of frequency on the endurance limit of a wide range of materials when tested in resonance.

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P. H. FRITH: 'Fatigue of Wrought High-Tensile Alloy Steels.'

*Session* 5, Paper 7; 41 pp.

For the purpose of this paper a high-tensile steel is defined as one having a longitudinal ultimate tensile strength of over 60 tons per sq. in. The information given comprises a total of 287 fatigue limits, including data previously published by Gough, Thurston, Frith and others, and unpublished data obtained in the author's laboratory. The fatigue results given are for various types or combinations of reversed stress, but no data are included for reversed stress superimposed on a static stress.

The tests reported were made on five different types of fatigue-testing machines, and the classes of steel covered were low-alloy chromium-molybdenum, low- and medium nickel-chromium and nickel – chromium – molybdenum, nickel – chromium-molybdenum-vanadium, low-chromium, high-chromium containing molybdenum (with or without tungsten or cobalt), and tungsten – chromium – vanadium high-speed steels.

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J. M. LESSELLS and R. F. BRODRICK: 'Shot-Peening as Protection of Surface-Damaged Propeller-Blade Materials.'

*Session* 8, Paper 1; 13 pp.

Aircraft propeller blades, like some other aircraft parts, are subjected to many cycles of alternating load during service. Design strength must therefore be based on fatigue data rather than on other mechanical properties. The design of the blades is further complicated by the fact that they are usually exposed in service to surface damage by impingement of foreign material, such as grit from runways, etc., and the areas in which this damage occurs may act as stress raisers, giving rise to fatigue failure.

Considerable attention has been given to methods for treating propeller blades to lessen damage from such extraneous sources, and among the methods considered has been the possibility of providing protection by development of a residual compressive stress in the blade surface, e.g., by peening. This paper reports results of experiments with this method of cold working.

The first phase of the work involved study of residual stress distribution under various conditions of shot peening, carried out on a low-alloy nickel-chromium-molybdenum steel tested in three different degrees of hardness. Reverse-bend fatigue tests on this steel, shot-peened to various depths and

subjected to artificial damage, lead to the conclusion that such treatment, if properly controlled, considerably improves the fatigue strength of damaged surfaces.

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E. R. GADD: 'Fatigue in Aero-Engines.'
*Session* 8, Paper 5; 16 pp.

It is now well known that surface finishes and treatments have a profound effect on the behaviour of metals under cyclic stress. The variables which may thus affect fatigue-resistance are considered in this paper, with special reference to conditions existing in aircraft gas-turbine engines. Tables give typical examples of the effect of high temperatures on the tensile strength, endurance limit, and stress-to-rupture of a number of gas-turbine materials.

The causes of fatigue failure are first discussed from the mechanical standpoint. Methods used for inspection and examination of gas-turbine blades before, during, and after service, are reviewed, in relation to prevention of susceptibility to fatigue failure.

Variables influencing susceptibility to fatigue are then discussed:—

Effect of Surface Finish
Surface Hardening (Shot-peening, nitriding and carburizing)
Surface Coatings (Electrodeposited, phosphate and organic types).

Later sections of the paper are concerned with the importance of fatigue data, fatigue anomalies in the behaviour of engine components *vis-à-vis* laboratory test data, and the future development of high-temperature materials.

**Influence of Impurities on Embrittlement in Nickel-Alloy Steels**

K. BALAJIVA, R. M. COOK and D. K. WORN: 'Effects of Trace Elements on Embrittlement of Steels.'
*Nature*, 1956, vol. 178, Aug. 25, p. 433.

Investigations on the factors causing embrittlement in a wide range of commercial steels have shown that the Charpy impact-transition ranges were raised (in all cases, but to varying degrees) if the steels were exposed at 450°C. for lengthy periods. In many instances the transition range still remained below room temperature after exposure at 450°C., i.e., the materials were not brittle at room temperature.

It has long been suspected that trace elements are an important factor in relation to embrittlement, and experiments reported in this note confirm the significance of this variant. A commercial 3 per cent. nickel-chromium steel (B.S. En 23 type), oil-quenched as $\frac{5}{8}$-in. diameter bar from 840°C., tempered at 625°C. and water-quenched, showed a Charpy V-notch impact transition range extending from −35° to +150°C. After re-heating the hardened and tempered steel at 450°C. for 168 hours, and water-quenching, the impact transition range was from 230° to −20°C.

Comparative tests were made on a steel of the same nominal composition, but prepared from carbonyl iron powder and other specially pure raw materials in powder form. In this steel, oil-quenched from 840°C., tempered at 650°C. and water-quenched, the impact transition range was −60° to −200°C., and the range was unaffected by exposure of the steel for 1,000 hours at 450°C. A further specimen of the same nominal composition, made from similar raw materials, was melted and cast in vacuo. After treatment identical with that undergone by the high-purity material mentioned above, this steel also showed an impact-transition range of −60° to −200°C. which remained unchanged after exposure for 1,000 hours at 450°C.

**Solubility of Nitrogen in Alloy Steels**

See abstract on p. 192.

**Scaling of Nickel Steels and Nickel-Iron Alloy**

K. SACHS: 'The Effect of Nickel Content and Furnace Atmosphere on the Scale Formed on Nickel Steels.'
*Metallurgia*, 1956, vol. 54, Sept., pp. 109–14.

The paper describes a study of the structure of the innermost layers of scale formed in various atmospheres on low-alloy nickel steels and on an alloy containing nickel 43, carbon 0·06, per cent., balance iron.

It is shown that this inner layer of scale contains nickel-rich metallic particles entangled with Wüstite. The amount of metal in the scale decreases with increasing partial pressure of oxygen in the oxide and with falling nickel content. The furnace atmosphere and the thickness of the scale determine the partial oxygen pressure at various levels in the scale and, therefore, the nickel content of the metal phase. A study was made also of the structural characteristics of scale formed on steel containing antimony as well as nickel.

**Microchemical Sorting Tests for Alloy Steels**

W. R. NALL and R. SCHOLEY: 'A Non-Destructive Microchemical Method of Sorting Steels.'
*Metallurgia*, 1956, vol. 54, Aug., pp. 97–102.

In sorting steels which have become unintentionally mixed, or in other circumstances calling for rapid determination of composition, two alternative methods are available.

Established non-destructive methods include spectrographic analysis and magnetic/electrical sorting, both of which give accurate results but involve the use of relatively elaborate apparatus. Spot-testing techniques, on the other hand, are purely qualitative, indicating the presence or absence of an element.

The method proposed in this paper is a compromise between these two, and it is claimed to provide results which are a reliable guide to composition of steels. The procedure was developed as a result of modification of known electrographic technique and the development of a new piece of microchemical apparatus. The use of the method is described in relation to determination of manganese, chromium, molybdenum and nickel in carbon or low-alloy

steels, and it is suggested that the scheme can be extended to the determination of other alloying elements, e.g., copper, cobalt and titanium.

## HEAT- AND CORROSION-RESISTING MATERIALS

### Solubility of Nitrogen in Alloy Steels

F. C. LANGENBERG: 'Predicting the Solubility of Nitrogen in Molten Steel.'

*Jnl. of Metals*, 1956, vol. 8, Aug., Sect. I: *Trans. Amer. Inst. Mining and Metallurgical Engineers*, pp. 1099-101 T.P. 4263C.

During the past few years there has been increasing use of nitrogen as a major alloying element in steels, or as a partial substitute for other alloying elements. Nitrogen is a potent austenite stabilizer, and chromium-manganese-low nickel-nitrogen steels and other nitrogen-containing types are being considered, in some applications, as substitutes for stainless steels of higher metal-alloy content.

A survey of the literature has indicated a lack of basic research on the solubility of nitrogen in molten alloy steels, but results of investigations relating to binary iron alloys were utilized in development of the method which is described in this paper. Reference is given to the original researches so used.

The examples given to illustrate the procedure recommended include determination of nitrogen in high-alloy chromium-manganese and nickel-chromium austenitic steels.

### Ageing Phenomena in Austenitic Nickel-Chromium-Molybdenum Steel

A. FERRO, S. GALLO and C. P. GALOTTO: 'Ageing of 16-25-6 Steel and Identification of the Precipitates Formed.'

*Metallurgia Italiana*, 1956, vol. 48, Aug., pp. 361-8.

The precipitates formed on ageing of a 16-25-6 chromium-nickel-molybdenum steel were extracted electrolytically, and examined by X-ray diffraction and by electron-microscope methods. The kinetics of the precipitation of carbides and nitrides were investigated by dilatometric methods and by measurements of changes in the lattice of the matrix.

### Nickel Alloys in Aircraft

HENRY WIGGIN AND CO., LTD.: 'Wiggin Nickel Alloys in Aircraft.'

Publn 1114,* 1956; 56 pp.

The information contained in this publication is given in sections relating to the respective alloy groups and each section is well illustrated, showing typical uses. The scope is indicated below:—

*The Nimonic Series* (Nickel-chromium-(cobalt)-base alloys).

Used for turbine rotor and stator blades, turbine discs, flame tubes, afterburners, exhaust units, gas-turbine rings, rocket motors, ramjets, and other miscellaneous applications.

*Inconel* (Nickel-chromium-iron alloy).

Used in insulating blankets, ramjets, exhaust manifolds and other applications.

*Monel* (Nickel-copper alloy).

Used for airframe rivets and fasteners, filtration equipment, anti-vibration mountings, hydraulic pipe-lines, liquid de-icing systems, and other applications.

*K Monel* (Nickel-copper-aluminium alloy).

Used for airframe rivets and bolts, electrically-operated hydraulic valves, 'heat-barrier' skin plating, and other purposes.

*Nickel*

Used in electronic transmitting and receiving valves.

*The Brightray Series* (Nickel-chromium and nickel-chromium-iron alloys).

Used in electrothermal de-icing equipment, in fire-detection devices, and for the coating of exhaust valves.

*The Nilo Series* (Nickel-iron-(cobalt) alloys).

Used in glass-to-metal seals, in high-energy ignition plugs, and for high-temperature skin plating.

*Ferry* (Copper-nickel alloy).

Used for electrical resistances and other applications.

*Ni-Span C* (Nickel-iron-chromium-titanium alloy).

Used for springs.

*Mangonic Alloys* (Nickel-manganese alloys).

Used for electrode support wires in radio valves, for tungsten filament lamps and for grid winding wires, also for disc-type earth electrodes in sparking plugs.

*W.5, W.6, W.7 and W.8* (Nickel-silicon-manganese alloys).

Used for the central electrodes of sparking plugs.

*Thermometals*

Used for control of temperature and pressure.

*Wrought Alloys made by Powder Metallurgy*

Used where extremely high purity and unusually close control of properties is essential, e.g., alloys used for control of thermal expansion, and for cathode materials in special types of thermionic valves.

### Etchants for Revelation of Sigma Phase

I. BERTETTI: 'New Electrolytic Reagents for Etching of Stainless Steels containing Sigma Phase.'

*Metallurgia Italiana*, 1956, vol. 48, July, pp. 324-6.

Report of study of reagents suitable for use with stainless steels of the types shown in the table on p. 193.

On the ferritic straight-chromium steels good results were obtained with solutions of ammonium persulphate, sodium perborate, sodium periodate, and sodium bromate. For austenitic steels positive revelation of sigma phase could be obtained only by use of ammonium persulphate and sodium bromate.

* *We shall be pleased to supply a free copy of this publication.*

**Stainless Steels used in Etching Tests**

| | C % | Si % | Mn % | Cr % | Ni % | Mo % | Ti % |
|---|---|---|---|---|---|---|---|
| I .. .. | 0·15 | 1·02 | 0·49 | 30·77 | 0·43 | — | 0·20 |
| II .. .. | 0·07 | 0·41 | 1·54 | 17·55 | 11·20 | 2·05 | — |

### Effect of Cold Work on the High-Temperature Properties of Austenitic Steels

R. A. LULA, A. J. LENA and H. M. JOHNSON: 'Effect of Cold Work on Elevated-Temperature Properties of Types 301, 305 and 310 Stainless Steels.'

*Amer. Soc. Mechanical Engineers*, Paper 56-SA-44, June 1956; 7 pp.

The capacity of austenitic stainless steels for work-hardening has been utilized to advantage for structural applications at room temperature. The investigation reported here was carried out to provide information which would indicate the potential value of cold-working for material to be used in high-temperature applications.

The steels used were of the compositions shown on p. 194.

Particular interest centred on Type 301, which transforms partially to martensite during cold-rolling: the other grades were included to provide wider coverage of the possible structural changes which can occur in the austenitic stainless steels at elevated temperatures. Carbide precipitation in the range 1000°–1600°F. (540°–870°C.) occurs in all three steels, but only in Type 310 does extensive sigma formation take place.

The steels, in the form of annealed strip, were cold-rolled to various degrees, and determinations were made on the materials in all conditions, of (*a*) room-temperature properties, and (*b*) stress-rupture characteristics.

From the results it is concluded that:—

In all three steels, cold-working increases the rupture strength, provided that the degree of cold-work and the conditions of exposure are not conducive to extensive recrystallization.

The lower the temperature of test, the greater is the increase in strength derived from cold-working.

Optimum amount of cold-work depends on temperature and time of test: it decreases with increasing time at a given temperature or with increasing temperature for a given time.

The beneficial effect of cold-working on high-temperature strength persists during the recovery period prior to recrystallization.

Recrystallization results in a substantial fall in high-temperature strength of cold-worked austenitic stainless steels: the decrease in rupture strength due to recrystallization is caused by structural modifications occurring during that process. These changes include effect on grain size and carbide distribution in all the steels, and acceleration of sigma formation in Type 310. Martensite produced by cold-rolling of unstable austenitic steels, such as Type 301, transforms to austenite at the temperatures of test and cannot contribute to strength at high temperatures.

### Complex Nickel-Chromium-base Electrical-Resistance Alloys

A. H. M. ARNOLD: 'Nickel-Chromium-Aluminium-Copper Resistance Wire.'

*Proc. Instn. Electrical Engineers*, Part B, 1956, vol. 103, July, pp. 439–47.

The qualities required in a resistance alloy are reviewed, and the resistance/temperature characteristics of typical alloys are discussed in relation to such requirements. The various types of alloy which have been used as resistance materials are first considered, with particular reference to Manganin and to improved alloys which have been developed to obviate certain limitations inherent in that material. Detailed attention is then given to materials characterized by specially high resistivity, *viz.*, nickel-chromium-base alloys.

By addition of minor amounts of aluminium, copper, iron and other elements, the stability of these alloys has been improved, and heat-treatment has been simplified.

Two alloys of modified types are of particular interest. The one, commercially known as Evanohm, has an approximate composition of nickel 73, chromium 21, aluminium 2, copper 2, per cent., with minor amounts of other metals; the other, designated Karma, is closely similar in composition, except that the copper is replaced by iron. Both of these alloys have a resistivity three times that of Manganin, a thermal e.m.f. to copper generally less than that of Manganin, high tensile strength, and a temperature coefficient of resistance which can be controlled by heat-treatment at moderate temperatures.

Results of tests made at The National Physical Laboratory on these two materials have indicated that the copper-containing type is more stable than the iron-containing alloy. This paper reports extensive experiments on the copper-containing variety.

The stability of resistors of this type of material

**Steels used in Cold-Working Experiments**

| Type | C % | Si % | Mn % | Cr % | Ni % | $N_2$ % | Cu % |
|---|---|---|---|---|---|---|---|
| 301 | 0·11 | 0·30 | 0·76 | 17·83 | 7·17 | 0·046 | 0·24 |
| 305 | 0·072 | 0·31 | 1·04 | 17·79 | 11·58 | 0·052 | — |
| 310 | 0·065 | 0·35 | 1·40 | 24·58 | 19·86 | 0·050 | 0·16 |

has been found to be generally of the order of a few parts in $10^5$ per year, and it is hoped that even better figures may be obtained in well-aged standards of the alloy. Stability is not adversely affected, and may even be improved by operation at temperatures up to 120°C. Above 140°C. there is usually an increase of resistance, but even at 400°C. the change is not rapid. Operation above that temperature is not recommended, even for low-accuracy resistors.

### Impact Tests on Nickel-bonded Titanium-Carbide Cermets

E. J. SOXMAN, J. R. TINKLEPAUGH and M. T. CURRAN: 'An Impact Test for Use with Cermets.'

*Jnl. Amer. Ceramic Soc.*, 1956, vol. 39, Aug. 1, pp. 261–5.

The paper describes an increment-impact (repeated-blow) test developed at Wright Air Development Center specifically for evaluation of cermets over a range of temperature. The validity of the method has been critically examined, in eight laboratories, by means of tests of a nickel-bonded titanium-carbide cermet.

### Inconel-Cemented Titanium Carbide

See abstract on p. 185.

### Influence of Vanadium and Sodium Compounds on Corrosion of Stainless Steel

G. W. CUNNINGHAM and A. DE S. BRASUNAS: 'The Effects of Contamination by Vanadium and Sodium Compounds on the Air Corrosion of Stainless Steel.'

*Corrosion*, 1956, vol. 12, Aug., pp. 389t–405t.

The main aim of the comprehensive investigation reported was a study of the mechanism by which deterioration results from contact with compounds formed from oils containing vanadium, with or without sodium. It is now generally agreed that the reaction consists in destruction, by certain contaminants, of the corrosion-resisting oxide layer which normally forms on the surface of heat-resisting materials. This reaction consists in the formation of a pervious complex or mixed oxide by reaction of atmospheric oxygen and contaminants, such as vanadium pentoxide, with the metal surface. The reaction product, being no longer an effective barrier to diffusion, permits the corrosion reaction to proceed unimpeded, and accelerated corrosion occurs at rates which may be considered 'catastrophic'.

The earlier literature is critically reviewed by the authors, and a summary is made of the methods which, on a theoretical basis, may be used to solve the problem. This is followed by a report of detailed experimental work. The tests were in two series: (1) preliminary investigation of the resistance to attack offered by eight chromium-iron and chromium-nickel-iron-base alloys, and (2) more exhaustive tests on an alloy of the following composition:—carbon 0·056, chromium 18·15, nickel 9·18, silicon 0·40, manganese 1·13, per cent. In stage (1) none of the materials showed adequate resistance. In stage (2) the influence of the following factors was investigated, as affecting the *amount* of corrosion suffered:—quantity and nature of contaminant (including especially the effect of the presence of sodium+vanadium), time of exposure, presence of inhibiting additives, phosphate coatings, influence of reducing furnace atmosphere in retarding attack.

From the widely varied data recorded, the following conclusions are drawn:—

(1) A molten oxide film is necessary for the promotion of accelerated corrosion. At temperatures below the melting point of the contaminant, normal corrosion is encountered.

(2) If a limited quantity of low-melting contaminant is present and is not replenished, the corrosion rate will decrease.

(3) A critical amount of ash is necessary for initiation of accelerated attack. This amount is approximately 0·1 g. per sq. in. of surface area, but the amount varies with composition of the ash and other variables.

(4) There may be an incubation time (i.e., a period required for the ash to react with the thin oxide film normally formed) before the contaminant becomes active.

(5) The oxide scale formed under such conditions is porous and allows free access of atmospheric oxygen to the molten oxide film at the metal-oxide interface, and this interface is the zone of reaction.

(6) Molten $Na_2SO_4$–$V_2O_5$ mixtures exhibit high absorbing power for oxygen. The mixtures having the maximum absorptive power lie in the range 16–20 wt.% $Na_2SO_4$, and this is also the most corrosive mixture.

(7) On solidification, molten $Na_2SO_4$–$V_2O_5$ mixtures will reject the absorbed oxygen to the atmosphere, but the absorbed oxygen is available in the molten mixture for reaction with metal, as indicated in the mechanism proposed below, see (15).

(8) In the vanadium-rich mixtures, the rate-controlling step at constant temperature appears to be the rate at which oxygen passes through the molten film to the metal surface.

(9) $Na_2O$–$V_2O_5$ mixtures behave similarly to $Na_2SO_4$–$V_2O_5$, but appear to be slightly more corrosive, as judged by effects on 18–8 chromium-nickel steel.

(10) $Na_2SO_4$–$V_2O_5$ mixtures slowly decompose to the more corrosive $Na_2O$–$V_2O_5$ mixtures.

(11) During the early stages of exposure carbon decreases the rate of corrosion caused by the vanadium-rich ashes: its presence increases the rate of attack of sodium-sulphate-rich ashes, especially in the case of high-nickel alloys.

(12) With regard to inhibitors, it is observed that calcium, barium and strontium oxides are always beneficial, and that magnesium oxide is frequently beneficial as an admixture with vanadium-rich ash. Silica additions, up to 18 per cent., appear to do no good.

(13) Duriron (high-silicon iron alloy) was the only material tested which resisted accelerated corrosion.

(14) Phosphate coatings on heat-resisting alloys are beneficial, provided that adherence can be assured.

(15) The unusually high corrosion encountered when 80 per cent. $V_2O_5$ - 20 per cent. $Na_2SO_4$ is present as contaminant on the surface of a heat-resistant alloy at temperatures above 1500°F. (815°C.) is caused by the reaction between metal and the oxygen dissolved in the molten contaminant, according to the following reaction:—

Metal + High $O_2$ Contaminant → Metal Oxide + Low $O_2$ Contaminant.

Thus, the molten layer appears to act primarily as an oxygen carrier and a destroyer of protective films.

**Influence of Composition of Alloys on Resistance to Attack by Vanadium Pentoxide**

E. FITZER and J. SCHWAB: 'Attack of Scaling-Resistant Materials by Vanadium Pentoxide and Effect of Various Alloying Elements Thereon.'

*Corrosion*, 1956, vol. 12, Sept., pp. 459t–64t.

The nature of the attack by vanadium pentoxide and other compounds is briefly discussed and three theories which have been advanced to account for the accelerated oxidation are reviewed.

Preliminary tests made by the authors, combined with a consideration of service experience and published data, led to the conclusion that any adequate accelerated test method should provide for uniform and well-defined temporary wetting with molten $V_2O_5$, or for the covering of the specimens with that oxide. In the test described, these conditions were ensured by adopting a certain periodicity between the attack by molten $V_2O_5$ and by pure oxygen. The apparatus and procedure are described in detail and are illustrated. Essential features are that the specimens are scaled for 15-minute periods in an oxygen stream at 925°C. while being indirectly heated in a vertical tubular furnace. The oxidation cycles are interrupted by brief immersions in molten $V_2O_5$ (at 900°C.). Such intermittent treatment can be continued as long as is desired, being limited only by the life of the specimens. Weight loss after each cycle is determined. It was found that this method achieves a perfectly uniform attack, which is almost linear with time: a very accurate estimate of the stability of the test material can be obtained after two cycles, and only the most resistant materials could be exposed to a five-hour total attack.

Using this rapid technique, comparative tests were made on established scaling-resistant alloys of iron or nickel base, and on some binary nickel-iron and iron-silicon alloys. Weight losses observed after the various test periods lead the authors to the following conclusions with regard to the influence of the individual alloy elements present in the test materials:

Chromium acts favourably only when present in relatively large proportions.

Silicon has a highly beneficial effect.

Pure nickel behaves better than iron, but the amount of nickel present in chromium-nickel steels appears to exert no effect.

The favourable effect of silicon is probably due to the absolute resistance of $SiO_2$ or silicate layers to attack by molten $V_2O_5$, whereas with chromium alloys the carrier of the scaling resistance (the stable oxide layer) is destroyed by the formation of low-melting chromium and/or iron-chromium vanadates. It is suggested that the known susceptibility of high-silicon alloys to brittleness, which severely limits their serviceability, can be obviated by impregnating the surface of tougher materials, such as austenitic chromium-nickel steels, with silicon. More detailed discussion of this method of inhibiting attack is to be published in a later paper, in which the authors will also discuss the diffusion behaviour of silicon in chromium and chromium-nickel steels. The

opinion is, however, expressed that the work now reported has already demonstrated that the problem of scaling by $V_2O_5$ can be at least partially solved by a metallurgical approach.

### Corrosion by Vanadium Pentoxide

V. CIRILLI, A. BURDESE and C. BRISI: 'High-Temperature Corrosion of Metals by Vanadium Compounds. (1) Researches on the Systems Metal-Vanadium-Oxygen.'

*Metallurgia Italiana*, 1956, vol. 48, July, pp. 309-16.

With a view to studying corrosion caused by contact of vanadium oxides with metals at high-temperature, investigation was made of the equilibrium diagrams of vanadium oxides with iron-, chromium-, nickel-, and cobalt- oxides. In the $Cr_2O_3$-$V_2O_5$ and the $Fe_2O_3$-$V_2O_5$ systems a single compound appears, the orthovanadate, but in the systems $CoO$-$V_2O_5$ and $NiO$-$V_2O_5$ the ortho-, pyro-, and metavanadates are observed.

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A. BURDESE and C. BRISI: 'Corrosion of Metals at High Temperatures by Vanadium Anhydride.

Part II. Behaviour of the Metals Iron, Cobalt, Nickel and Chromium and their Alloys',

*ibid.*, Aug., pp. 349-57.

On the basis of results obtained in Part I, a study was made to identify the compounds present in the corrosion products formed on the materials mentioned when they are attacked by vanadium dioxide.

### Alloy for Steam-Turbine Blading: Nivco

P. M. UNTERWEISER: 'New Blading Alloy Improves Turbine Performance.'

*Iron Age*, 1956, vol. 178, Sept. 6, pp. 100-1.

Steels which have previously been satisfactory for steam-turbine blading are proving inadequate under the increasingly rigorous conditions in which the newer and more efficient turbines operate. The call is for a blading material which will combine high strength at temperatures above 1000°F. (540°C.) and good damping capacity. This latter requirement is the more difficult to satisfy, and the material described in this article has been evolved mainly as a result of research on the factors influencing damping capacity in a high-temperature alloy. In the initial stages of the investigation an answer to the problem was found in an effect designated 'magneto-mechanical hysteresis'. Essentially, this effect in ferromagnetic materials links the direction of an imposed stress with the magnetic orientation of ferromagnetic domains. Mechanical stress can, by itself, alter the direction of magnetization. When this change occurs, domain structure is altered, energy is dissipated, and damping is actually improved.

The extent of the improvement depends mainly upon the chemical and structural nature of the material. Other considerations which have to be satisfied are that the alloy must be precipitation-hardenable (to secure the requisite strength), and ferromagnetic, that it must possess a Curie temperature above 1200°F. (650° C.), and must respond readily to irreversible magnetostriction. Studies of the structure and known properties of various alloys pointed to a basis composition of cobalt 65, nickel 35, per cent. as likely to be suitable and the requisite balance of properties has been obtained by further modification with suitable minor amounts of other alloying elements.

It is claimed that the new alloy, Nivco, has a 100-hour creep-rupture life of about 50,000 p.s.i. (22·30 tons per sq. in.) at 1200°F. (650°C.), and that at that temperature its measured damping capacity is about ten times greater than that of many of the special high-temperature alloys, at vibrational tensile stresses between 5,000 and 10,000 p.s.i. The endurance limit at the same temperature is in the region of 45,000 p.s.i. (20 tons per sq. in.).

### Pitting Corrosion in Austenitic Nickel-Chromium Steel

M. A. STREICHER: 'Pitting Corrosion of 18 Cr—8 Ni Stainless Steel.'

Part I. Development of an Accelerated Pit Initiation Method.

Part II. Investigation of Variables in the Metal and in the Electrolyte which Control Pit Initiation.'

*Jnl. Electrochemical Soc.*, 1956, vol. 103, July, pp. 375-81: 381-90.

In Part I the author reviews factors controlling pitting corrosion, and laboratory methods which may be used for the study of the phenomenon. A description is given of an electrolytic accelerated test developed in the laboratory of E.I. du Pont de Nemours and Company, Inc. In this test a controlled direct current is passed through a cell the anode of which is the stainless-steel specimen, and in which the electrolyte is the pitting solution. The number of pits formed was found to depend on the current density, the composition and surface treatment of the steel, and the composition and temperature of the test solution.

In Part II the electrolytic pitting test was used for determination of the influence of alloying elements in 18-8 chromium-nickel steel exposed in sodium chloride and bromide solutions. It was observed that reduction in carbon content, increase in nitrogen content and additions of molybdenum and silicon increased resistance to the initiation of pits. Grain boundaries, rather than non-metallic inclusions, were found to be the primary sites on which pitting started, both during simple immersion and in the electrolytic accelerated test.

### Stress-Corrosion Cracking in Nickel-Chromium Stainless Steel

H. L. LOGAN and R. J. SHERMAN: 'Stress-Corrosion Cracking of Type 304 Austenitic Stainless Steel.'

*Welding Jnl.*, 1956, vol. 35, Aug., pp. 389s-95s.

Although no serious failures of stainless-steel equipment have yet been attributed directly to stress-corrosion cracking, metallurgists and chemical

engineers have recently become increasingly aware that a large proportion of leaks developing in such equipment are due to this cause. It is recognized that such leaks represent a considerable loss to industry, not only in capital replacement but also in lost time and products, and the Pressure Vessel Research Committee has therefore sponsored, at the National Bureau of Standards, an investigation of the mechanism of stress-corrosion cracking in austenitic stainless steels.

This paper presents some of the results which have already been obtained in this research. The tests were limited to two types of nickel-chromium stainless steel, standard '18-8' and low-carbon '18-8'. Both steels were tested in sheet form and the low-carbon grade in rod form also.

A full account is given of the test equipment and technique: the experiments involved critical evaluation of 40 solutions with regard to their ability to cause stress-corrosion cracking. A boiling sodium-chloride/ammonium-nitrite solution ($3\frac{1}{2}/1\%$), used at a pH of 7·0, proved particularly discriminating. Immersion in this solution produced stress-corrosion cracking in a few hours in the standard steel stressed in tension to 80 per cent. or more of its room-temperature yield strength, but it was necessary to stress the low-carbon steel to 100 per cent. of its yield strength in order to produce stress-corrosion cracking in similar conditions.

A stress-corrosion crack was found in a 0·20-in. gauge length of a specimen which had been strained as little as 0·52 per cent., but there was no correlation between the amount of strain in a given gauge length and the presence of cracks.

In solutions of a pH below 4·0 pitting was the general type of corrosive attack, but stress-corrosion cracking could be obtained at a higher pH. Increasing the pH of the sodium-chloride/ammonium-nitrite solution from 7·0 to 8·5 increased susceptibility in the low-carbon steel, but had little effect on the standard grade. It was observed that in some instances stress-corrosion cracking developed with little or no previous pitting.

Hydrogen was given off during the corrosion process, and, as boiling of the solution continued, increasing amounts of nitrogen were evolved, indicating that the $NH_4NO_2$ was being broken down into $N_2$ and $H_2O$.

It is postulated that stress-corrosion cracking of the stainless steel results from rupturing of the passive film by the application of stress under conditions favourable to the formation of oxygen-concentration cells.

### Resistance of Stainless Steels to Mixed Nitric and Sulphuric Acids

P. E. KRYSTOW and M. BALICKI: 'Behaviour of 18-8 Stainless Steel in 2-Normal Boiling Nitric and Sulphuric Acid Mixtures.'

*Corrosion*, 1956, vol. 12, Sept., pp. 449t-54t.

An acid mixture commonly employed in many nitrating processes in the chemical industry is one containing nitric and sulphuric acids, and handling of nitrating acid mixtures, strong and dilute, hot and cold, often calls for the use of stainless steels. It is well known that austenitic stainless steels corrode rapidly in dilute sulphuric acid, whereas exposure to nitric acid results in almost negligible corrosion. It might therefore be anticipated that increased corrosion-resistance would be obtained by the addition of nitric acid to a dilute solution of sulphuric acid, and such modification is in some cases made, to lessen attack. The general behaviour of austenitic steels in the mixed acids is not, however, well established, and it is the purpose of this paper to report the results of studies on this subject. The material used was an annealed 18-8 chromium-nickel steel.

The results show that steels of this type, when exposed to a range of boiling 2-*N* sulphuric and nitric acid solution, pass first through a passive zone, in which corrosion is negligible, then through a transition zone, where corrosion is irregular, and finally through two active zones, in which corrosion is substantial. Corrosion rates in the passive and active zones were such as would be anticipated, but comment is made on certain unexpected phenomena observed in the transition zone: these are attributed to excessive corrosion of chromium at that stage.

### Corrosion of Nickel-Chromium Stainless Steel by Hypochlorite Solutions

C. BIGHI and G. PANCALDI: 'On the Corrosion of 18-8-Cr-Ni-Ti, 18-8 and 18 Cr-Ti Stainless Steels in Hot Solutions of Common Hypochlorite.'

*Metallurgia Italiana*, 1956, vol. 48, Feb., pp. 73-81.

Report of accelerated corrosion tests in various hypochlorite solutions. Particular attention was devoted to the effect of welding on the resistance of the steels to attack: the nature of the corrosion products formed on the welded samples was examined by colorimetric analysis.

### Atmospheric Corrosion of Non-Ferrous Metals

AMER. SOC. TESTING MATERIALS: 'Symposium on Atmospheric Corrosion of Non-Ferrous Metals.'

*A.S.T.M. Special Tech. Publn.* No. 175.
Published by the Society 1956; 158 pp.

This volume contains the papers and discussion presented at the symposium held in June 1955. Most of the communications are based on results obtained in tests carried out by the American Society for Testing Materials over a period of over 20 years. One of the objects of this series was to determine the correlation, if any, between tests of an accelerated laboratory type and atmospheric corrosion: a further aim was to evaluate the usefulness of changes in tensile properties as a measure of corrosion.

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W. H. FINKELDY: 'Introduction', pp. 1-2.

Remarks on the scope of the symposium and the investigations on which the papers are based.

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H. R. COPSON: 'Report of Sub-Committee VI, of Committee B-3, on Atmospheric Corrosion', pp. 3–19.

Report of 20-year tests on 24 non-ferrous metals and alloys, exposed at seven locations representing different types of atmosphere. The materials exposed included:—

Commercial coppers
Copper–silicon–manganese alloy
Tin, aluminium, and manganese bronzes
Commercial aluminium and various aluminium alloys
Brasses
Admiralty metal
Copper–nickel–zinc alloy (75–20–5 per cent.)
Copper–nickel–tin alloy (70–29–1 per cent.)
Nickel–copper alloy (65–32 per cent. with small amounts of iron and manganese)
'T' Nickel (99+% nickel)
Commercial lead
Commercial zinc (two grades)
Commercial tin
Lead–antimony alloy
Aluminium-coated Duralumin

The changes undergone as a result of atmospheric exposure are assessed in terms of weight-loss and average rate of corrosion, tensile properties, and ductility. No attempt is made in this report to analyze the data or compare the behaviour of various materials: such comparison is provided for by other contributions to the symposium.

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C. J. WALTON and W. KING: 'Resistance of Aluminum-base Alloys to 20-year Atmospheric Exposure', pp. 21–44; disc. pp. 45–6.

For aluminium alloys, in all environments, the effects of weathering, as measured by depth of attack and loss in tensile strength, generally decreased with time. Particular attention is directed to the outstanding performance of Alclad material, as demonstrating the excellent overall resistance to corrosion which can be achieved through the use of clad products.

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F. M. REINHART and G. A. ELLINGER: 'Effect of 20-year Marine Atmosphere Exposure on Some Aluminum Alloys', pp. 47–64; disc. pp. 65–6.

In urban and marine atmospheres aluminium alloys containing magnesium, manganese or cadmium, or clad alloys containing copper were the most resistant to corrosion over a period of up to 22 years. An alloy containing copper, manganese and silicon was the least resistant. Improperly quenched or aged alloys of aluminium and copper were highly susceptible to intergranular corrosion and rapid disintegration unless the surfaces were adequately protected. Anodically formed inorganic coatings were the most protective type of surface treatment.

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A. W. TRACY: 'Effect of Natural Atmospheres on Copper Alloys: 20-Year Test', pp. 67–76.

This paper analyzes the results on eleven copper-base alloys (for details of composition see paper by COPSON, above).

Corrosion rates, as determined from weight losses in 10 and 20 years' exposure, are correlated with tensile strength values before and after test. The resistance of copper alloys to corrosion in atmospheric conditions is largely a function of the type of corrosion product formed. In most atmospheres copper and its alloys form a thin adherent stable film of corrosion products, which eventually limits the rate of corrosion to the rate of solution of the film. The tension data gave a useful indication of dezincification. The extent of pitting corrosion was negligible.

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D. H. THOMPSON, A. W. TRACY and J. R. FREEMAN: 'The Atmospheric Corrosion of Copper: Results of 20-Year Tests', pp. 77–87; disc. p. 88.

Report of tests on eleven brands of copper sheet and wire, exposed to four outdoor atmospheres. The purest coppers corroded least and the arsenical coppers were worst attacked, but the differences were of no practical significance. The mean corrosion rate was found to be of the order of $50 \times 10^{-6}$ in. per year.

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H. O. TEEPLE: 'Atmospheric Galvanic Corrosion of Magnesium Coupled to Other Metals', pp. 89–115.

Study of the behaviour of two magnesium alloys coupled with aluminium- and copper-base alloys, Monel, nickel, nickel-chromium corrosion-resisting steel, zinc, and cadmium- and zinc-plated steel.

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K. G. COMPTON and A. MENDIZZA: 'Galvanic Couple Corrosion Studies by Means of the Threaded Bolt and Wire Test', pp. 116–123; disc. pp. 124–5.

Illustrated description of the test, and report of results obtained by it on various galvanic couples including nickel, Monel and nickel-chromium steel members.

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E. A. ANDERSON: 'The Atmospheric Corrosion of Rolled Zinc', pp. 126–34.

Critical survey of the data presented in the report of the Corrosion Committee, see paper by COPSON, above.

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G. O. HIERS and E. J. MINARCIK: 'The Use of Lead and Tin Outdoors', pp. 135–40.

Chemical lead and antimonial lead were found to be remarkably durable under the conditions used in the tests. Losses in strength of some of the specimens, due to inadequate support in the test racks, emphasizes the known need for knowledge and skill in the use of hard and soft lead for architectural purposes.

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H. R. COPSON: 'Atmospheric Corrosion Behaviour of Some Nickel Alloys', pp. 141–58.

Summary of the results on Monel and nickel, as contained in the report of the Corrosion Committee (see pp. 3–19), together with results obtained in independent atmospheric corrosion tests made by The

International Nickel Company on nickel, Monel, nickel-iron, nickel-chromium and nickel-chromium-iron alloys, and stainless steel, in an industrial atmosphere at Bayonne, N.J.

Evaluation of the data from the two series of tests leads to the following conclusions:—

'Nickel and high-nickel alloys are very resistant to corrosion at marine and rural locations: in severe industrial locations the corrosion is more pronounced. In the case of nickel, nickel-copper alloys, and nickel-iron alloys high in nickel the attack is essentially uniform in nature and the corrosion rate is constant with time. In alloys containing appreciable amounts of chromium the attack is local and of a pitting type. Sheltered specimens corrode more than boldly exposed specimens, and screen and wire corrode faster than sheet.

'The behaviour of nickel-copper alloys varied with location. At marine locations nickel corroded less than copper, and additions of nickel to copper were beneficial. At industrial locations nickel corroded more than copper, and substantial additions of nickel to copper increased the corrosion. Monel corroded less than nickel boldly exposed. These results seem in accord with the polarity of galvanic couples of nickel and copper.

'In the nickel-iron series, additions of up to 20 per cent. of iron to nickel decreased the corrosion somewhat at an industrial location: with larger amounts of iron the corrosion increased. With sufficiently high iron content, however, adherent rust coatings formed, which were protective, and this caused the corrosion rates to decrease with time, to fairly low values. Nickel steels form protective rust coatings and corrode much less than plain steels.

'Chromium additions to nickel decreased the corrosion markedly, but the attack tended to localize and become of a pitting type. A sheltered exposure condition considerably increased the pitting. The addition of iron to nickel-chromium alloys decreased the pitting and made the attack more uniform, but the presence of iron revealed itself in rusty corrosion products.

'In the case of corrosion-resistant stainless steels, chromium content was the most important factor in determining corrosion behaviour on bold exposure: heat-treatment and surface finish were of minor importance, as compared with chromium content. Boldly exposed in an industrial atmosphere, the usual grades of stainless steel containing molybdenum remained unattacked. The harmful effect of shelter and the beneficial effect of molybdenum were pronounced in the case of stainless-steel screen.'

**Resistance of Nickel-containing Bronzes to Attack by Softened Water**

L. E. TABOR: 'Effects of Softened Water on Equipment.' *Reprint* from *Jnl. Amer. Water Works Assocn.*, 1956, vol. 48, Mar.; 8 pp.

This paper reports investigations made following failures in valve stems operating in softened-water systems in Los Angeles. The deterioration was traced to dezincification.

Tests of various materials, in waters of varying composition (full details of analysis given), showed that the following factors affected deterioration of this type:—percentage of zinc in the alloy, electrical conductivity of the water, galvanic couples or electrical currents, other alloying components, availability of oxygen, pH value of the water, and the presence of chemicals in the water. The extent of the effect of each of these variables was studied on various bronzes, and other copper-base materials, and from the results the following conclusions are drawn:—

No bronzes subject to selective dissolution should be used, under any conditions, in softened water. In view of the need for high strength in materials for such applications, certain stainless steels were considered, but were rejected as unsuitable, due to cost and machining difficulties. Beryllium-copper is regarded as too expensive. Silicon-bronze appears satisfactory, except that machining and handling in the foundry is difficult.

Particularly promising results were shown by copper-base alloys of the Ni-Vee type, containing nickel 5, tin 5, zinc 2, per cent., balance copper. These bronzes can be heat-treated to high strength, and tests have shown no evidence of any susceptibility to selective dissolution in water systems.

**Fatigue Investigations on Nickel-containing Materials**

See abstract on p. 190.

**Cobalt-base Alloys and Stainless Steels in Dentistry**

W. TOFAUTE: 'Chromium-Nickel Steel, Cobalt-Chromium-Molybdenum Alloys and Nickel-containing Cobalt-Chromium Alloys for use in Dental Prosthesis.'

*Tech. Mitt. Krupp*, 1956, vol. 14, Aug., pp. 54–9.

Review of the mechanical and physical properties and corrosion-resisting qualities of the materials mentioned, with special reference to their use in dental prosthesis. Casting properties, work-hardening characteristics and annealing behaviour are also considered, as affecting the suitability of these materials for such applications.

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R. HALBACH: 'Methods for Working Nickel-Chromium Steel and Cobalt-Chromium Alloys used in Dental Prosthesis', *ibid.*, pp. 60–7.

Sections of this paper cover, respectively, methods suitable for mechanical working of these materials, annealing, welding and soldering, precision casting and electropolishing. The production of wire is also dealt with.

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J. JANTZEN: 'Clinical Experience with Nickel-Chromium Steel, Cobalt-Chromium-Molybdenum Alloys and Nickel-containing Cobalt-Chromium Alloys in Dentistry', *ibid.*, pp. 68–76.

Various applications are discussed and illustrated and the relative suitability of the alloys for individual uses is critically evaluated.

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H. D. DIETZE: 'Special Mechanical Properties of Dental Bracing Wires of Nickel-containing Chromium-Cobalt Alloys', *ibid.*, pp. 77–80.

Report of tests to determine the tensile properties of wire of a 25-30-45 per cent. nickel-chromium-cobalt alloy.

### Stainless-Steel Weights

E. R. HARRISON: 'Some Tests on the Stability of 25-20 Stainless Steel for Analytical Weights.'

*Australia Dept. of Supply, Defence Standards Laboratories*, Tech. Note 18, pp. 1–7, 1953.

*Chemical Abstracts*, 1956, vol. 50, July 25, p. 9795.

Report on behaviour of 100-g. weights of stainless steel, naval brass and ordinary brass, exposed to the following tests:—

(1) Storage under normal conditions.

(2) Immersion for about one year in cold and hot distilled water and afterwards for one month in an acid-fume cupboard.

The stainless-steel specimens were also subjected, after the fume test, to a month in ammonia fumes.

The weight changes in both types of brass were heavy, but the stainless-steel weights lost only 0·26 mg., mainly while under exposure to the acid fumes.

The conclusion is drawn that austenitic nickel-chromium steel weights are very suitable for use in analytical laboratories and as reference standards of mass.

### Nickel and Nickel-Alloy Welding Rods and Electrodes

See abstract on p. 185.

### Austenitic Nickel-Chromium Steel Electrodes for Welding High-Manganese Steels

W. F. LUTES and H. F. REID: 'Comparative Properties of Electrodes for Arc Welding Austenitic Manganese Steels.'

*Welding Jnl.*, 1956, vol. 35, Aug., pp. 776–83.

The article briefly describes the general characteristics of the various types of work-hardened austenitic materials used for fabrication and build-up of high-manganese steels. The physical and mechanical properties of weld metal deposited by typical commercial electrodes in each category are compared. The types of electrodes examined were:—

High-manganese steel containing small percentages of nickel

High-manganese steel containing low percentages of molybdenum

High-manganese steel containing low percentages of chromium and molybdenum

Austenitic chromium-nickel-manganese steel.

The tests showed that each type of weld metal had specific advantages and limitations: the variations in properties of the individual deposits suggest the need for greater care in selecting the best material for a particular application. In general the nickel-containing electrodes gave good results.

## PATENTS

### Composite Welded Nickel Anodes

Uniformity of corrosion in the welded and the unwelded portions of composite sheet anodes is secured by using electrolytic nickel for both the sheets and the weld metal and by subjecting the welded anode to heat-treatment within the range 1400°–2100°F. (760°–1150°C.) for a sufficiently long period to effect equalized grain growth in and around the weld.

W. L. PINNER and O. D. HOXIE, assignors to HOUDAILLE-HERSHEY CORPN. *U.S. Pat.* 2,729,580.

### Bright Nickel-Plating Solutions

An acid bath for bright nickel plating contains at least one nickel salt, 0·001–0·05 g./L. of 2-mercapto-benzimidazole or its derivatives, and 0·2–25 g./L. of a secondary brightener, preferably a sulphonated aryl compound. A typical solution contains $NiSO_4$ 300, $NiCl_2$ 52, $H_3BO_3$ 40, naphthalene-1,3,6-trisulphonate of Na 20, 2-mercapto-benzimidazole 0·01, g./L. Operating conditions are pH 3·5, temperature 130°F. (55°C.), current density 30 amp./sq. ft.

F. PASSAL, assignor to UNITED CHROMIUM, INC. *U.S. Pat.* 2,737,484.

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An acid bright nickel-plating bath contains at least one nickel salt and coumarin sulphuric, with an unsaturated methylene sulphanyl. Saccharin in small amounts may also be present.

UDYLITE RESEARCH CORPN. *Brit. Pat.* 758,162 (similar to *U.S. Pat.* 2,694,041).

### Electrodeposition of Nickel on Magnesium and Magnesium Alloys

Magnesium and high-magnesium alloys are prepared for plating with nickel by de-filming in an acidulated aqueous solution containing a fluoride. The material is then rinsed in water and, without drying, is electroplated in an aqueous bath containing nickel bifluoride and hydrogen fluoride, with 10–50 g./L. of citric or tartaric acid and/or the alkaline-eartch compounds of these acids. The solution is used at a pH of 1–3, and is operated at 125°–140°F. (52°–60°C.) at a current density of 30–100 amp./sq. ft.

H. K. DE LONG, assignor to DOW CHEMICAL CO. *U.S. Pat.* 2,728,720.

### Bright Nickel-Chromium Electrodeposited Coatings

Bright nickel-chromium coatings are deposited from a bath containing (g./L.) chromic acid 150–350, nickel chloride 13–60, where the ratio of chromium to nickel is 4–14:1. The bath is worked at a current density of 400–2000 amp./sq. ft. and a temperature below 40°C. Glacial acetic acid (3–10 g./L.) may also be present, or propionic, citric, formic or oxalic acids may be used in place of the acetic acid. Immersion

of the plated surface in a solution of hydrochloric acid is also covered, for treatment of coatings on which a blackened surface is required.

M. F. QUAELY, assignor to WESTINGHOUSE ELECTRIC CORPN. *U.S. Pat.* 2,739,108.

### Black Nickel-Chromium-Vanadium Electrodeposited Coatings

Black coatings are electrodeposited from a bath containing (g./L.) chromic acid 150–350, nickel chloride 13–60, and a soluble compound of vanadium, 2–10 g./L. Glacial acetic acid may also be present. The solution is operated at a current density of 400–2000 amp./sq. ft., at a temperature below 40°C.

M. F. QUAELY, assignor to WESTINGHOUSE ELECTRIC CORPN. *U.S. Pat.* 2,739,109.

### Nickel-Rhenium Alloys in Thermionic Valves

Supports used in thermionic valves are made from a nickel-rhenium alloy containing up to 30 per cent. of rhenium. The preferred rhenium content is 8 per cent.

ÉTAT FRANÇAIS, represented by MINISTRE DES POSTES, TÉLÉGRAPHES ET TÉLÉPHONES (CENTRE NATIONALE D'ÉTUDES DES TÉLÉCOMMUNICATIONS) et ÉTABLS. C. BERTOLUS. *French Pat.* 1,117,317.

### Ductile Heat-Resisting Nickel Alloy

A boron-free heat-resisting alloy capable of being rolled to sheet contains chromium 14–17, iron 8–12, molybdenum 4–7, titanium 2·25–5, aluminium 0·75–2·5, carbon 0·08–0·25, per cent., nickel balance. It is specified that the ratio of Ti:Al shall be 1–1·5:1. Information on the properties of typical alloys, within various temperature ranges, are given, and the use of such materials for turbine blading is mentioned.

ELECTRIC FURNACE PRODUCTS CO., LTD., assignee of I. S. SERVI and H. R. SPENDELOW.
*Brit. Pat.* 751,556 (similar to *French Pat.* 1,103, 237).

### Electrical-Resistance Alloy

A resistance alloy of improved type contains chromium 10–30, silicon 1·25–6, manganese 0·4–6, per cent., nickel balance. The resistance exceeds 1 ohm/mm²/m. and the temperature coefficient is less than 0·0001 ohm/ohm/°C. over the range −50° to +250°C.

A. B. KANTHAL. *French Pat.* 1,112,619.

### High-Alloy Heat-Resisting Steel

A steel claimed to have high load-carrying capacity at elevated temperatures contains carbon 0·28–0·35, manganese 0·75–1·5, silicon 0·3–0·8, chromium 18–21, nickel 8–11, molybdenum 1–2, tungsten 1–2, titanium 0·4–0·9, per cent., iron balance.

UNIVERSAL-CYCLOPS STEEL CORPN. (inventor, C. T. EVANS).
*Brit. Pat.* 752,124 (similar to *U.S. Pat.* 2,677,610).

### Fatigue-Resistant Steel for Use at High Temperatures

Steels showing lessened tendency to embrittlement under fatigue loading above 500°F. (260°C.) contain carbon up to 0·1, nickel 16–20, chromium 12–18, molybdenum 1–3, tantalum and/or niobium up to 1·2, per cent., iron balance. (It is specified that the tantalum and/or niobium shall be present in sufficient amount to combine with all the carbon in the steel.) Molybdenum may be wholly or partly replaced by vanadium.

DEUTSCHE EDELSTAHLWERKE, A.G.
*Brit. Pat.* 758,623.

### Steels Resistant to Attack by Vanadium Pentoxide

Steels claimed to be resistant to attack by $V_2O_5$ present in crude petroleum contain carbon 0·21, chromium 10–45, silicon 4–11, nickel up to 30 per cent., iron balance. Up to half of the chromium may be replaced by aluminium, and specified small amounts of the following metals may also be present:—tungsten, molybdenum, vanadium, titanium, tantalum, niobium, boron, cobalt.

SCHOELLER-BLECKMANN STAHLWERKE, A.G.
*Brit. Pat.* 758,009.

### High-Expansion Austenitic Steel

A forgeable austenitic steel having a thermal coefficient of expansion of at least $11{\cdot}8 \times 10^{-6}$ in./in./°F. between 70° and 700°F. (20° and 370°C.), and a hardness of at least Rockwell C 28, contains carbon 0·5–0·7, nickel 6–7, manganese 5–9, chromium up to 0·5, silicon up to 1, per cent., iron balance.

P. PAYSON, assignor to CRUCIBLE STEEL CO. OF AMERICA *U.S. Pat.* 2,739,057.

### Brazing of Titanium Alloys

Titanium alloys are bonded to other metals or alloys by the use of solder based on a nickel-titanium eutectic. Small amounts of copper and chromium may also be present.

R. A. LONG. *Brit. Pat.* 752,117.

### Production of Lubricant-carrying Coatings on Nickel-containing Materials

Wires, bands or other products of iron, steel, nickel, cobalt or their alloys (including nickel-chromium stainless steels and nickel-copper alloys) are immersed or sprinkled with an aqueous solution containing one or more hydroxides, and are subsequently annealed to provide a lubricant-absorbing coating, which aids in the cold working of the materials. In an example quoted, wire of a nickel-chromium-iron alloy is dipped into an aqueous suspension containing NaOH 25, $NaNO_3$ 5, lime 7, per cent.

VEREINIGTE DEUTSCHE METALLWERKE, A.G.
*Brit. Pat.* 750, 896.

**Attention is drawn to the fact that many of the names of materials mentioned in The Nickel Bulletin are *Registered Trade Marks.***

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